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USING A CLUSTER-WIDE SHARED REPOSITORY TO PROVIDE  
THE LATEST CONSISTENT DEFINITION OF THE CLUSTER  
(AVOIDING THE PARTITION-IN-TIME PROBLEM)

RELATED APPLICATIONS

This application discloses subject matter also disclosed in the following  
compending applications:

Serial No. \_\_\_\_\_, filed May 28, 1999, entitled A QUORUMLESS CLUSTER  
USING DISK-BASED MESSAGING, by Richard Frank, Michael Cusson, Joydip  
Kundu, and Daniel E. O'Shaughnessy, inventors;

Serial No. \_\_\_\_\_, filed May 28, 1999, entitled AVOIDING N-SQUARED  
HEARTBEAT MESSAGING PROBLEM IN AN OPERATING CLUSTER VIA  
CLOSED LOOP MESSAGING THEME, Richard Frank, Michael Cusson, Joydip  
Kundu, and Daniel E. O'Shaughnessy, inventors; and

Serial No. \_\_\_\_\_, filed May 28, 1999, entitled PROVIDING FIGURE OF  
MERIT VOTE FROM APPLICATION EXECUTING ON A PARTITIONED  
CLUSTER, by Richard Frank, Michael Cusson, Joydip Kundu, and Daniel E.  
O'Shaughnessy, inventors.

The entire teachings of the aforementioned, compending applications are  
incorporated herein by reference.

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## BACKGROUND

As is known in the art, a computer network cluster is a collection of interconnected computers which share resources such as data storage. The individual computers, or nodes, are connected through both a physical and a software-level  
5 interconnect. The independent nodes are integrated into a single virtual computer, appearing to an end user as a single computing resource. If one node fails, the remaining nodes will handle the load previously handled by the failed node. This multiple computer environment provides many benefits to a user including high availability and increased speed of operation.

10 A typical network cluster configuration includes a plurality of nodes typically sharing one or more storage devices. The nodes are connected to each other by a high speed network connection such as ethernet.

A user can connect into the network cluster through any of the nodes in the network cluster. From the perspective of a user, the network cluster appears as a single  
15 computer system. Software applications run by a user are executed using the shared storage devices. An exemplary software application often executed on a computer network cluster is a database application. Typically, the database is stored on one or more shared storage devices. Inquiries or changes to the database are initiated by a user through any one of the cluster member nodes.

20 Successful operation of a network cluster requires coordination among the nodes with respect to usage of the shared resources as well as with respect to the communication between the nodes. Specifically, with multiple users manipulating shared data, precautions must be taken in a network cluster to insure the data is not corrupted. In addition, instances of nodes joining and exiting the network cluster must  
25 also be coordinated to avoid a loss of system integrity. Multiple safeguards have been instituted to aid in the prevention of a loss of system integrity.

One such safeguard may be instituted by the network cluster to handle cluster partitioning. Cluster partitioning results when the cluster network degenerates into multiple cluster partitions including a subset of the cluster network nodes, each cluster

partition operating independently of each other. These partitions may be the result of miscommunication resulting from nodes joining or exiting the network cluster, the so-called partition-in-time problem.

The partition-in-time problem occurs when a node is absent from an operating  
5 network cluster for a period of time and the node has an invalid description of the  
operating parameters of the network cluster. For example, a network cluster is  
operating under a parameter where each node is scheduled to send heartbeat messages  
every second. A node, previously a member of the network cluster and currently  
rejoining the cluster, expects to send its heartbeat messages every three seconds as that  
10 had been the heartbeat messaging time interval when it was last a member of the cluster.  
As a result, the new node sends its heartbeat message every three seconds rather than  
every second. Accordingly, the network cluster continually attempts to resolve  
membership of the cluster as the remaining nodes assume the network connection to the  
new node was lost because a heartbeat message from the new node was not received by  
15 the remaining nodes every second. By continually resolving membership of the  
network cluster, user applications would be unnecessarily stalled and valuable system  
resources would be wasted.

To resolve such a problem, metadata is typically generated and stored which  
includes information that defines the cluster. Information typically included are the  
20 identities of the nodes which have permission to join the network cluster, the identity of  
the nodes which are currently operating in the network cluster, a time interval for  
sending heartbeat messages and the like. This metadata is provided to each member of  
the network cluster upon joining the cluster. In this manner a joining node would be  
made aware of the current operating parameters of the cluster upon joining.

## 25 SUMMARY

The safeguard described above provides a limited solution to the problem  
described. For instance the metadata detailing the cluster definition is typically kept in  
stable storage. To determine the cluster definition, a node would be required to have

network connectivity with the cluster and would then be provided, by the network connection, the cluster definition for the network cluster. A drawback to this approach is that a node needs to have network connectivity with the cluster before the node can be provided with the definition for the cluster.

- 5           Moreover, as a network cluster operates, changes to the cluster definition may be made by a cluster administrator. These changes must be communicated to each node. In the case where a node is unavailable to the cluster for a period of time, changes to the definition are stored during the nodes period of unavailability. This often requires a log file to be maintained enumerating all changes to a cluster definition made while one or
- 10   more nodes within a cluster are unavailable. As nodes may occasionally be removed from the cluster for maintenance, the log file could grow to a substantial size during the period of maintenance.

- The present system includes a method and an apparatus for providing a common storage for the cluster definition which does not require network connectivity to
- 15   propagate changes or to access the definition upon joining. A single node can be designated as the coordinator of the cluster definition and may be the only node which can make updates to the definition. Each node may have a scratch area in which it provides changes to the cluster definition. The coordinator node applies the suggested changes to the shared definition. When a node wishes to rejoin a cluster, it reads the
- 20   common storage to access the current cluster definition before needing to establish network connectivity with the cluster.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of Using a Cluster-wide Shared Repository to Provide the Latest Consistent Definition of the Cluster (Avoiding the Partition-in-Time Problem), as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. For clarity and ease of description, the drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a diagram of a quorumless computer network cluster operating in accordance with the present system.

FIG. 2 is a diagram depicting a relationship between multiple software components residing on each node of the quorumless computer network cluster of FIG. 1.

FIG. 3 is a diagram representing the exchange of heartbeat messages between the nodes of the quorumless computer network cluster of FIG. 1.

FIG. 4 is a block diagram of a repository located in the shareable storage of FIG. 1.

FIG. 5 is a flow diagram describing a process for updating a cluster definition stored in the repository of FIG. 4.

FIG. 6 is a flow diagram describing a process for reading the cluster definition stored in the repository of FIG. 4.

FIG. 7 is a flow diagram describing a process for resolving a partitioned cluster.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a diagram of a quorumless computer network cluster operating in accordance with the present system. It should be understood that a quorumless network cluster 10 can have any number of nodes. As illustrated, an example quorumless network cluster 10 is shown as having four nodes, node\_1 12, node\_2 14, node\_3 16 and node\_4 18 connected to each other through a high speed network connection 20. The four nodes 12, 14, 16, 18 are further connected to shareable storage 22 through a storage connection 24. In the quorumless network cluster 10, access and membership in the cluster is predicated on an individual node having access to the shareable storage 22.

According to a certain embodiment of the invention, a computer network cluster can form if one of the four nodes 12, 14, 16, 18 has access to the shareable storage 22. As described in the background, previous network clusters required a quorum of nodes to be available to form a cluster. That is, if four nodes were approved members of a cluster, at least three of the nodes,  $(N+1)/2$  where N is the number of nodes permissibly in the cluster, must be operating as members in the cluster for the cluster to continue operation.

Here, contrary to a traditional quorum cluster, a single node can form a cluster. The single node, for example, node\_1 12, can access the shareable storage 22, extract cluster definition data from the storage, as will be described in detail below, and form a computer network cluster. At a later time, node\_2 14, node\_3 16 and node\_4 18 can join the already established cluster. Moreover, if node\_2 14, node\_3 16 and node\_4 18 subsequently exit the cluster, the cluster may continue to operate even though fewer than a quorum of nodes is in current operation in the cluster. Such an arrangement can increase availability of the cluster to a user by minimizing shutdowns of the computer network cluster initiated by fewer than a quorum of nodes being in operation.

Here, shareable storage 22 has been illustrated as a single storage disk or the like. It should be understood by one of ordinary skill in the art that the shareable storage may include multiple storage devices. To implement multiple storage devices as the shareable storage 22, a header 25 of each storage device may include data

indicating the identity of all devices comprising the shareable storage 22, a version number for information contained in the header 25, and any other pertinent data. To gain membership in the quorumless cluster 10, a node must have access to all storage devices comprising the shareable storage 22.

- 5           To determine whether, for instance node\_1 12, has access to all storage devices, node\_1 accesses the information contained in the header in the storage device it believes to be part of the quorumless cluster 10. Assume that two storage devices comprise the shareable storage 22, disk A and disk B (not shown). The header of each disk would include a label (A, B, 1) indicating that disk A and disk B are members of the valid
- 10       storage set and that this definition is version 1. Node\_1 12 accesses the information contained in the header of disk A and realizes that to join the quorumless cluster 10 it needs to have access to both disk A and disk B. Disk B's header information can be accessed to verify that the valid storage set had not been altered.

- During subsequent operation of the quorumless cluster 10, one or more of the
- 15       member nodes 12, 14, 16, 18 may lose access to disk A. In such a case, it may be decided by the member nodes 12, 14, 16, 18 of the quorumless cluster 10 to drop disk A from the cluster. The header information in disk B is edited to read (\_, B, 2) indicating that only disk B comprises the shareable storage 22 and that this is the second version of the valid storage set. If another node attempted to join the cluster at this time it could
- 20       access the header file in disk A which indicates that access to both disk A and disk B is required to gain membership in the cluster 10. If the node did not have access to disk B it would not be able to join the quorumless cluster 10. If the node checked the header information in disk B it would correctly determine that only access to disk B is required to join the quorumless cluster 10.

- 25           Typically, communications on the computer network cluster 10 are directed by logical layers of software. These software layers reside on each individual node. Corresponding layers communicate with peer layers on other nodes within the computer network cluster 10 to coordinate activities of the nodes. Here, the layers of software

which are of specific interest are the cluster (or communication) manager, (CM), the distributed lock manager, (DLM), and a distributed software application.

FIG. 2 is a diagram depicting a relationship between multiple software components residing on each node of the quorumless computer network cluster of FIG.

- 5 1. Referring now to FIG. 2, a block diagram 30 is shown depicting a representation of some of the software layers residing on node\_1 12. It should be noted that the layers depicted on node\_1 12 have counterparts on each of the remaining nodes 14, 16, 18 of the network cluster 10. A cluster manager 32, a distributed lock manager 34 and a distributed application 36 are shown to reside on node\_1 12. As shown, the cluster
- 10 manager 32 may operate in concert with the distributed lock manager 34 and the distributed application. That is, the distributed application 38 and the DLM 34 of node\_1 12 use the services provided by the cluster manager 32 while executing on node\_1 12.

- Specifically, the cluster manager 32 manages cluster connectivity in the
- 15 computer network cluster 10. For example, the cluster manager 32 can oversee the addition of nodes to and removal of nodes from the computer network cluster 10. It can also prevent the cluster 10 from partitioning into multiple cluster partitions. In addition, as an entity, such as an application or distributed lock manager, begins operating on node\_1 12 and within the quorumless cluster 10, the entity may register with the cluster
- 20 manager 32. Registration with the cluster manager 32 signifies that the entity requests that changes in cluster membership, among other things, be communicated to the entity by the cluster manager 32.

The distributed lock manager 34 synchronizes operations between the nodes on shared resources. Supervision of shared resources by the DLM 34 is voluntary.

- 25 Distributed applications request the DLM 34 to coordinate access by the applications to shared resources.

Specifically, the distributed application 36 requests the DLM 34 to synchronize its operations on shared resources with operations of peer distributed applications on other nodes. Here, an exemplary shared resource is the file system 38. That is, the



distributed application 36 may have access to file systems (not shown) residing on other nodes 14, 16, 18 as distributed applications residing on other nodes 14, 16, 18 may have access to the file system 38 residing on node\_1 12. The DLM 34 locks out distributed applications of the other nodes 14, 16, 18 from the shared resource 38 while the  
5 distributed application 36 is using the resource.

In addition, data residing on the shareable storage device 22 of FIG. 1 may also be shared by the multiple distributed applications. The DLM 34 of node\_1 12 locks out distributed applications of the other nodes 14, 16, 18 from data being accessed by the distributed application of node\_1 12 within the shareable storage device 22.

10 Accordingly, only a single application may be using a shared resource at a single time.

As described above, the cluster manager 32 manages the cluster connectivity. One aspect of managing the connectivity of the cluster is monitoring the membership of the cluster. Specifically, the cluster manager 32 manages cluster integrity when nodes are added to or removed from the cluster.

15 FIG. 3 is a diagram representing the exchange of heartbeat messages between the nodes of the quorumless computer network cluster of FIG. 1. Referring now to FIG. 3, a logical arrangement of the nodes 12, 14, 16, 18 of the computer network cluster 10, here referred to as a status cascade 40, is shown which facilitates monitoring membership of the quorumless cluster 10. As discussed previously, nodes in a  
20 computer network cluster continually monitor the other nodes in the cluster to know whether another node has ceased operation within the cluster. As a means for monitoring the membership status of the nodes in the cluster, heartbeat messages are sent from each node to each other node in the cluster. If a node failed to receive a heartbeat message from one of the other nodes within a predetermined time interval, the  
25 cluster would enter reconfiguration mode. In reconfiguration mode, all user applications executing on the network cluster are stalled until the cluster membership is once again verified.

In the prior art arrangement, it would be common for a cluster to require each node to send its heartbeat messages at one second intervals, or even more often. For an

N node cluster, this would require sending  $(N-1)^2$  heartbeat messages every second. This heartbeat messaging traffic consumes valuable processor time within the cluster. Processor time which would be better used by user applications.

In an effort to reduce the heartbeat messaging traffic in the computer cluster 10, node\_1 12, node\_2 14, node\_3 16 and node\_4 18 are configured in a closed loop arrangement in which each node has a logical previous node and a logical next node. That is, within the status cascade 40, the previous node to node\_1 12 is node\_4 18 and the next node for node\_1 12 is node\_2 14. Each node transmits a single heartbeat message to its next node and receives a single heartbeat message from its previous node. This arrangement reduces the number of heartbeat messages in the four node cluster of the quorumless computer network cluster 10 to four heartbeat messages every predetermined time interval.

Each node 12, 14, 16, 18 in the status cascade 40 is shown to include both a message receiver 42a-42d and a message transmitter 44a-44d. In accordance with the invention, node\_1 12 sends a heartbeat message from its message transmitter 44a to the message receiver 42b of node\_2 14. Node\_2, simultaneous with the message transmission of node\_1 12, sends a heartbeat message from its message transmitter 44b to the message receiver 42c of node\_3 16. Likewise, node\_3 16 and node\_4 18 send and receive heartbeat messages to and from their respective next and previous nodes.

Should any of the nodes 12, 14, 16, 18 fail to receive a heartbeat message from its previous node, it sends a cluster reconfiguration message from its message transmitter 44a-44d to each other node in the quorumless cluster 10. In reconfiguration mode, the quorumless cluster 10 reverts to an open loop arrangement in which each node sends a heartbeat message to each other node until node membership is once again reconciled.

In one embodiment, the ordering arrangement of the nodes can be predicated on a unique node id assigned to each node within the quorumless cluster. The nodes are ordered sequentially in the closed loop, the node having the highest node id providing its heartbeat message to the node having the lowest node id, thus serving to close the

messaging loop. Other methods of ordering the nodes would also prove capable of providing a comparable closed loop arrangement, such as assigning sequential ordinal numbers to each node and arranging the closed loop based on the ordinal numbers.

As described above in conjunction with FIG. 2, the cluster manager 32, in concert with the cluster managers residing on nodes 2 - 4 14, 16, 18, manages cluster connectivity within the quorumless cluster 10. For the cluster managers to effectively cooperate in the connectivity management endeavor, a facility for sharing data is provided. The shareable storage device 22 of FIG. 1 houses a repository for this data sharing facility.

FIG. 4 is a block diagram of a repository located in the shareable storage of FIG. 1. Referring now to FIG. 4, the shareable storage device is shown to include, *inter alia*, a repository 46 which facilitates data sharing among the cluster managers for each node 12, 14, 16, 18 of the quorumless cluster 10. Node\_1 12, node\_2 14, node\_3 16 and node\_4 18 are also depicted to illustrate the areas of the repository 46 to which the cluster manager of each node is granted write privileges. The repository 46 includes, *inter alia*, a cluster definition 48, a scratch area 50, a map file 52, a log 54, an update in progress flag 56 and a version number 58. Each of these components may be used by the cluster managers to maintain a cluster definition for the quorumless cluster 10.

By way of background, an initial definition for a network cluster is typically provided by a cluster administrator before the network cluster is formed, by manually entering cluster parameters at a terminal to be stored in a storage device. For the quorumless cluster 10, these cluster parameters are stored within the repository 46 located in the shareable storage device 22. Examples of types of parameters which are stored to form the cluster definition include the identities of nodes which are permissible members of the network cluster, the identify of nodes which are currently operating in the network cluster and a time interval for each member node to send a heartbeat message.

Prior solutions for providing the cluster definition to each member node of a network cluster typically fell into one of two schools of thought. Under the first school

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of thought, a single shared copy of the cluster definition was provided for a network cluster. To determine the cluster definition, a node would be required to have network connectivity with the cluster and would then be provided, by the network connection, the cluster definition for the network cluster. A drawback to this approach is that a node  
5 needs to have network connectivity with the cluster before the node can be provided with the definition for the cluster.

Moreover, as a network cluster operates, changes to the cluster definition may be made by a cluster administrator. These changes must be communicated to each node. In the case where a node is unavailable to the cluster for a period of time, changes to the  
10 definition are stored during the nodes period of unavailability. This often requires a log file to be maintained enumerating all changes to a cluster definition made while one or more nodes within a cluster are unavailable. As nodes may occasionally be removed from the cluster for maintenance, the log file could grow to a substantial size during the period of maintenance.

15 Again, before the node can be provided with the definitional changes, it first needs connectivity with the network cluster. During this period of time of cluster connectivity until the latest definitional changes are communicated, the node is operating under an invalid cluster definition, possibly causing a partition in space problem which may, in turn, affect the integrity of the system.

20 Under the second school of thought, each node has a local copy of the cluster definition. Again, changes to the definition are communicated to each node, requiring network connectivity, so that the node may update its copy of the definition. As with the single shared definition version, there is a danger of a node operating under an invalid cluster definition and causing a partition in time problem.

25 According to an embodiment of the present system, a single shared copy of the cluster definition 48 is provided in the shareable storage device 22. Here, however, only access to the shareable storage device is required to access the definition rather than network connectivity with the cluster. When one of the nodes 12, 14, 16, 18 of the quorumless cluster 10 first attempts to join the cluster 10, it is provided with the

location of the repository 46 in the shareable storage device 22 from which it may determine a current quorumless cluster definition. The node can access the cluster definition 48 before establishing network connectivity with the cluster.

Upon formation of the quorumless cluster 10, one of the member nodes 12, 14, 16, 18 is designated as the coordinator node. Any method of selection which yields a designation of a single node as coordinator may be used. For example, one method for selecting a coordinator node is to select the first node to join the cluster. An alternate method is to select the node having the highest, or lowest, node id. For illustrative purposes, node\_3 16 has been designated as the coordinator node. The cluster manager of the coordinator node is responsible for making updates to the cluster definition 48.

As described above, changes to the cluster definition 48 are often made by a cluster administrator during operation of the cluster. Rather than providing each node 12, 14, 16, 18 with write privileges for the cluster definition 48, a single node is selected to coordinate all changes to the cluster definition 48.

In an alternate embodiment, the cluster definition is shown to include a first 48a and a second 48b copy (shown in phantom) of the cluster definition. The map file 52 (also shown in phantom) may store a designation indicating that one of these copies is a current cluster definition and the other copy is a backup cluster definition. Alternatively, either copy 48a, 48b may be accessed for the current cluster definition.

FIG. 5 is a flow diagram describing a process for updating a cluster definition stored in the repository of FIG. 4. A cluster administrator, connecting to the quorumless cluster 10 on node\_1 12, provides one or more changes to the cluster definition 48. These changes are entered into a section of the scratch area 50 allocated to node\_1 12 at step 60. The scratch area 50 is divided into four sections, each section allocated to one of the four nodes, node\_1 12, node\_2 14, node\_3 16 or node\_4 18. Each section includes an area in which cluster definition changes are entered 50a, 50b, 50c, 50d as well as a valid bit 51a, 51b, 51c, 51d.

Upon entering the proposed changes to the cluster definition 48 in the scratch area 50a, node\_1 12 sets the valid bit 51a to indicate that it has completed entering its

changes and notifies the coordinator node, node\_3 16, that it has proposed changes to the cluster definition 48 at step 62. The coordinator node, node\_3 16, verifies that the valid bit has been set and sets the update in progress flag 56 at step 64 to indicate that an update of the cluster definition 48 is in progress.

- 5           The coordinator node reads the scratch area 50a for the proposed changes at step 66 and increments the version number 58 of the repository to indicate a change is being made to the cluster definition 48 at step 68. At step 70, the coordinator node updates the cluster definition 48, to reflect the proposed changes. In addition, the coordinator node logs a progression of the update procedure in the log file 54. At step 72, the
- 10          coordinator node clears the valid bit 51a and the update in progress flag 56.

As described above, the cluster definition 48 may be comprised of multiple copies. See FIG. 4. Updates to multiple copies may be accomplished in the manner described above where step 68 is implemented in parallel across all copies of the cluster definition at once.

- 15           In an alternate embodiment including multiple copies of the cluster definition, the coordinator node reads the scratch area 50a and updates a backup definition 48b (as identified by the map file 52). When the update to the cluster definition 48 has been completed, the coordinator node modifies the map file to designate the second copy 48b as the current definition and the first copy 48a as the backup definition. A timestamp is
- 20          associated with the new current definition to signify a time at which the cluster definition 48 was updated. The coordinator node updates the former current definition, now backup definition 48a to reflect the proposed changes, again logging the progress of the update in the log file 54. Finally, the coordinator node clears the valid bit to indicate that the update is complete.

- 25           By writing proposed changes to the cluster definition 48 as a set by a single node, a situation in which multiple nodes are trying to make changes to the cluster definition in parallel is avoided. Parallel edits can result in a cluster definition which partially represents the changes made by a first node and partially represents changes made by a second node. That is, changes instituted by a first node may be overwritten

by changes made by a second node and vice versa resulting in a cluster definition which is not representative of either node's proposed definition. In addition, by using a single node to write the changes implements a serialization primitive to coordinate cluster definition changes rather than having to use the distributed lock manager 34 (FIG. 2) of node\_1 to synchronize changes to the cluster definition 48.

The log file 54 and valid bits 51a-51d provide a means by which the quorumless cluster can recover if, during an update to the cluster definition 48, the coordinator node fails to operate. Upon loss of the coordinator node, the remaining nodes, node\_1 12, node\_2 14 and node\_4 18, of the quorumless cluster 10 select a new coordinator node.

For illustrative purposes, it will be assumed that the remaining nodes designate node\_4 18 as the coordinator node. Upon designation as coordinator node, node\_4 18 checks the state of the repository 46 to determine whether an update to the cluster definition 48 was left incomplete by the failure of the former coordinator node, node\_3 16.

If a valid bit 51a-51d is set in the scratch area 50, the new coordinator node will examine the log file to determine whether an update had been started by the former coordinator node. If it was, the coordinator node parses the log file to determine where during the update process the former coordinator node failed. The new coordinator node completes the update from the identified point on.

As described above, a joining node needs to access the cluster definition 48 before joining the quorumless cluster 10. Here, it is assumed that node\_3 16 is now attempting to rejoin the quorumless cluster 10 after its prior failure.

FIG. 6 is a flow diagram describing a process for reading the cluster definition stored in the repository of FIG. 4. Referring now to FIG. 6, a procedure 75 for determining the current cluster definition is illustrated in flowchart format. At step 76, node\_3 16, the joining node, determines the version number 58 for the repository 46. At step 78, node\_3 16 checks the update in progress flag 56. If at step 80, node\_3 16 determines that the update in progress flag 56 is set, node\_3 16 will return to step 76, re-determine the version number 58 of the repository 46, check the update in progress flag

56 again, and cycle through steps 76 to 80 until the update in progress flag has been cleared by the coordinator node, indicating that an update to the cluster definition 48 has been completed.

At step 82, node\_3 16 determines the cluster parameters from the cluster  
5 definition 48. Node\_3 16, the joining node, again checks the version number 58 of the repository 46 at step 84. At step 86, node\_3 16 compares the version number determined at step 76 with the version number determined at step 84 and proceeds back to step 76 if they do not match. A non-match of the version numbers indicates that an update to the cluster definition began after the joining node checked the update in  
10 progress flag 56 but was completed before the joining node rechecked the version number 58 of the repository 46. If there was a match at step 86 however, the joining node has succeeded in reading a valid cluster definition and may join the quorumless cluster 10.

As described above, the cluster definition may be comprised of multiple copies.  
15 In an alternate embodiment, node\_3 16, the joining node, accesses the map file 52 (FIG. 4) to determine the location of a current cluster definition. Specifically, node\_3 16 determines which of the two copies of the cluster definition 48a, 48b is the current cluster definition.

Node\_3 16 proceeds to determine a first timestamp for the current definition 48b  
20 and read the cluster parameters from the current cluster definition 48b. When node\_3 16 has completed reading the current cluster definition 48b, it again determines the location of the current definition. A second timestamp for the current cluster definition 48b is determined by node\_3 16, which is compared to the first timestamp. If the two timestamps agree, node\_3 16 read a valid cluster definition and can now join the  
25 quorumless cluster 10. If however, the timestamps do not agree, this indicates that while node\_3 was reading the current cluster definition, the coordinator node, node\_4 18, was in the process of updating the cluster definition 48. Accordingly, node\_3 16 read a now invalid cluster definition. As a result, node\_3 16 repeats the process and begins by determining the location of the current cluster definition. In this way,



preference is given to a node updating the cluster definition over the node reading the cluster definition.

As described above, network connectivity between nodes in a cluster may occasionally be lost. When this occurs, there is a danger that cluster partitions, comprised of a subset of the member nodes of the cluster, may form, each cluster partition acting as the true network cluster. If the cluster partitions are allowed to continue operation, shared data may eventually be corrupted as no synchronization between the partitions is enacted for accessing the shared data. Accordingly, a single partition is selected to continue operating as the cluster while operation of the remaining one or more partitions is halted.

FIG. 7 is a flow diagram describing a process for resolving a partitioned cluster. Referring now to FIG. 7, a methodology 80 for resolving a partitioned cluster is illustrated in which a distributed application, executing on the quorumless cluster 10, is afforded an opportunity to provide a vote from which it is determined which cluster partition will continue operating. The methodology is shown to begin at step 82 where a cluster manager recognizes a change in cluster membership. One method for the cluster manager to recognize a change in membership indicating a partition-in-space problem is by noting changes being proposed by the nodes to the cluster definition which represent contradictory versions of the cluster membership.

It should be noted that although network connectivity may have been lost in the quorumless cluster 10, the cluster managers of each member node 12, 14, 16, 18 communicate to each other through disk based messaging, specifically through the repository 46 of FIG. 4. As described above, if a node loses access to the shareable storage 22, it removes itself from the quorumless cluster 10.

As also described above, entities, such as applications, may register with the cluster manager, to be informed of cluster membership changes. Assuming that an application executing on the quorumless cluster 10 had done so, it will be signaled by its node's cluster manager, at step 84, to pause operation.

At step 86, the cluster managers determine the status of the quorumless cluster 10. This includes sending heartbeat messages and the like among the various nodes to determine which nodes are still operating and which have network connectivity between them. At step 88, through an application program interface, (API), the cluster manager  
5 provides to the application a proposed figure of merit for the node the application is originating from. The application may accept the proposed figure of merit or propose an alternate figure of merit to the cluster manager also through use of an API.

The figure of merit is an indication of the value to the cluster manager or to the application, for its node to continue operating. The application may assess the nodes  
10 value in terms of any merit criteria the application deems appropriate. For instance, the application may determine the number of users currently executing the application and derive a figure of merit value based on number of users. Other criteria may be equally appropriate for such an evaluation such as a perceived execution priority of one application over another i.e., a payroll application vs. an accounts receivable billing  
15 application.

At step 90, the cluster managers for each of the nodes 12, 14, 16, 18 share the figure of merit data and determine, from the data, which cluster partition will continue operation. In addition to the figures of merit provided from the cluster manager and application, tie-breaker algorithms may also be employed. These tie-breakers include  
20 which nodes joined the cluster first, which node has the highest or lowest node id etc.

At step 92, based upon the decision made at step 90, the cluster managers resolve the quorumless cluster 10. Specifically, they halt operation of all non-selected cluster partitions. Once it is verified that the non-selected cluster partitions have all ceased operation, the cluster manager signals the application to resume operation at step  
25 94.

It will be apparent to those of ordinary skill in the art that methods involved in Using a Cluster-wide Shared Repository to Provide the Latest Consistent Definition of the Cluster (Avoiding the Partition-in-Time Problem) may be embodied in a computer program product that includes a computer usable medium. For example, such a

computer usable medium can include a readable memory device, such as a hard drive device, a CD-ROM, a DVD-ROM, or a computer diskette, having computer readable program code segments stored thereon. The computer readable medium can also include a communications or transmission medium, such as a bus or a communications  
5 link, either optical, wired, or wireless, having program code segments carried thereon as digital or analog data signals.

It will further be apparent to those of ordinary skill in the art that, as used herein, "node" may be broadly construed to mean any computer or component thereof directly or indirectly connected or connectable in any known or later-developed manner to a  
10 computer network cluster, such as over the Internet.

While this invention has been particularly shown and described with references to certain embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.